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**COMPUTER CONTROL OF ALUMINUM PRODUCTION**

(70)

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U.S.A.**

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Abstract of the Disclosure

Programmed digital computer control of the of aluminum by electrolysis is described. Charging o to individual reduction pots and changes in electrode are scheduled in accordance with monitored cell-resis current efficiency data, so that sick pots and anode averted, and more efficient operation of the reductio is obtained.

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The embodiments of the invention in which exclusive property or privilege is claimed are defined as follows:

1. A method for controlling the production of aluminum metal by the electrolysis of alumina fluxed cryolite and contained in a pot line, said pot line including a plurality of pots with each such pot having an anode electrode connected in series with a source of current, said method being characterized by the step

providing a plurality of adjustment positions for said anode electrode relative to the cathode electrode in each of said pots,

determining the current efficiency for each position in said line in relation to each said position of said anode electrode,

determining a maximized value of said current efficiency for each pot, and

positioning said anode electrode of each pot in accordance with said maximized current efficiency for each pot.

2. A method as defined in claim 1, further characterized by the steps of

providing at least one anode electrode and cathode

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with the equation

$$\%CE = \%CO_2 + \frac{\%CO}{2}.$$

4. The method of claim 1, including the steps of sampling the gases emitted from the anode electrode pot to determine the water vapor content of said gas, said current efficiency of each said pot being determined in accordance with the equation

$$\% CE = \%CO_2 + X \%H_2O + 1/2 [\%CO - Y \%H_2O]$$

where  $\%CO_2$  is the volume percentage of carbon dioxide,  $\%H_2O$  is the volume percentage of water vapor and  $\%CO$  is the volume percentage of carbon monoxide present in said gas being sampled, and X and Y are predetermined constants.

5. A process for controlling the production of aluminum metal by electrolysis in a plurality of pots, each pot containing a bath comprising alumina fused in cryolite and having an anode electrode and a cathode electrode, the electrodes of said pots being connected in series one another and across a power source, said process comprising the steps of

providing a plurality of positions for the anode electrode relative to the cathode electrode of each pot,

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$$\%CE = (\%CO_2 + \frac{\%CO}{2}) A \exp(-\frac{B}{T}), \text{ where } A \text{ and } B \text{ are}$$

predetermined constants and the base of the exponent function is the natural logarithm base e, and

controlling the anode electrode position for each pot in accordance with said determined current efficiency for that pot.

6. The method of claim 1, including the steps of:  
determining the integral of said current efficiency with respect to time for each pot in said line for providing an indication of the production of aluminum within said line;  
and controlling the position of said anode electrode for each pot in accordance with said integral current efficiency.

7. The method of claim 1, including the steps of:  
determining the differential of said current efficiency with respect to time for each pot in said line for indicating when the anode effect condition will occur relative to said pot, and

controlling the recharging of each pot with respect to the determined differential of said current efficiency for said pot.

8. A method according to claim 1, wherein:

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changes in said position,

means for determining the current efficiency of said one pot of said aluminum metal production for each said anode position in accordance with a predetermined relationship of the current utilization for producing aluminum metal,

means for determining the change in said current efficiency in relation to each predetermined change in the position of the anode electrode in said one pot,

and means for controlling said anode electrode position for said one pot in accordance with the respective changes in said current efficiency.

10. Apparatus for controlling aluminum production as set forth in claim 9,

with said means for controlling said anode electrode position being operative to maximize said current efficiency in accordance with said respective changes.

Background of the Invention

A 10

This invention relates to an improved control apparatus for controlling the reduction electrolysis in a molten salt bath.

It is the prior art practice to reduce electrolysis of alumina fluxed in cryolite, using individual furnaces or pots connected in series, using one or more carbon electrodes.

A typical aluminum reduction pot or furnace is essentially of a movable carbon anode, a cathode electrolyte of molten cryolite in which alumina is dissolved. The overall reaction occurring in the furnace consists of the reduction of alumina to aluminum, which is then deposited at the cathode, and the oxidation of carbon to carbon monoxide or carbon dioxide at the anode. The pot, in general, consists of a steel box lined with blocks of carbon, and containing a bath of molten cryolite, with carbon blocks positioned at the bottom and covered with molten aluminum to form a protective layer. Carbon anodes are movably suspended from above the bath of molten cryolite. An electrical power supply is connected between the anode and cathode, such that a current flows between the anode and the cathode to reduce the alumina to aluminum. The resulting molten bath, due to

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of the operation, becomes covered by a crust of frozer  
lyte and alumina. It is periodically necessary for ar  
to break away part of this crust and stir this broken  
rial into the bath, while fresh alumina is added above  
into a new crust. The electric current decomposes the  
in solution in the cryolite such that aluminum is depe  
the pool of molten metal already on the bottom of the  
In the course of the process oxygen is liberated at th  
of the anode where it reacts to form carbon dioxide wh  
10 off. The temperature of the operation is about 950°C.  
proportion of the aluminum reacts with the electrolyte  
a metal fog, which is carried to the anode by the circ  
of the electrolyte and is there oxidized to reduce som  
carbon dioxide to carbon monoxide.

According to Faraday's law, 1000 amperes of  
should produce in a typical reduction pot about 18 lbs  
aluminum per day; the usual practice provides only abc  
of metal being reduced, such that the efficiency of th  
in the process is about 85% and the anode gases conta  
20 30% carbon monoxide. The theoretical decomposition vc  
alumina to yield aluminum and carbon dioxide is 1.7 vc  
to the resistance of the electrolyte, the leads and th  
circuit connections. the furnace operates in practice

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and stirred into the bath such that it becomes dissolved  
make the electrolyte more conductive and the voltage of the  
furnace can then return to its normal value. Fresh alumina is  
added over the broken area to form a new crust. The tapping  
operation is required about every 8 hours, but the interval  
varies according to the design and method of operation of the  
furnace. Aluminum metal accumulates in a typical 40 kVA  
furnace at the rate of about 600 lbs. per day; at suitable  
intervals, daily or perhaps every other day, a tapping is  
brought to the front of the furnace and molten aluminum  
is drawn out of the furnace.

One kind of operating condition that can occur and  
needs correction is the so-called sick pot; this occurs when  
the alumina content of the molten salt bath becomes too low,  
either as a result of initially charging with too much carbon  
or the accidental addition of too much alumina during  
of an electrolysis operation. During a sick pot condition  
bath temperature drops abnormally and both the cell resistance  
and the current efficiency become too low. It is helpful in  
restoring a sick pot to normal operation, to raise the bath  
temperature and separate the electrodes of the pot in order to  
reduce the cell resistance to a value near a predetermined and de-

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the pot with a proper quantity of additional alumina.

In the aluminum industry, it has been common to provide the input power supply line with an ammeter, so that the current passing through the series connected pots could be detected, and to provide each pot with a voltmeter connected across its electrodes, so that the voltage drop across each pot and thereby the resistance in each pot or furnace could be determined. It has been known to adjust the position of the electrodes of an individual pot, in order that the efficiency of the current in that pot might thereby be improved, and it has been known for electrodes to be used that have embedded therein an iron or steel pipe, by means of which the anode gas could be sampled for analysis. The usual practice is to position the anode of each pot, in accordance with prior experience, to yield satisfactory cell-resistance values for the particular pot involved. Moreover, although there has been proper frequent and even substantially continuous addition of quantities of alumina to a pot, with the objective of keeping the alumina concentration in the pot more constant in relatively narrow limits and thereby maintain the efficiency at or near an optimal level, it has been more common to control the process by making relatively large

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$$\%CE \text{ (current efficiency)} = \%CO_2 + \frac{\%CO}{2}$$

as disclosed by Pearson et al and various modification including the modification of Kostyukov in accordance which the anode gas is also analyzed for water content order that a correction may be made for the water-gas-chemical reaction; the anode electrodes sometimes contains hydrocarbons, and hydrogen from the hydrocarbons react with carbon dioxide to yield carbon monoxide and water vapor. The McMinn paper further reports the work of Popov et al, in which by the use of the Pearson equation and electronic computing equipment, percentage current-efficiency values were calculated and used in process studies.

#### Brief Summary of the Present Invention

An improved operation for the production of aluminum by the electrolysis of alumina fluxed with cryolite attained in a plurality of series-connected pots is disclosed. Each pot is provided with a movable anode having a pipe therein, so that the anode gas generated along the bottom face of the anode may be sampled and analyzed. A programmatic computer means is provided to monitor the bath temperature and the bath resistance in each pot and to calculate, on the basis of the anode-gas analysis, the instantaneous efficiency.

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The prior art contains no appreciation of the particular desirability of using the improved techniques in aluminum production in accordance with the present invention nor of the magnitude of the benefits that are to be obtained in an electrolytic aluminum production operation by resort to the simultaneous practice of (1) automatic electrode position control to maximize current efficiency and (2) automatic regulation to achieve improved power factor.

Brief Description of the Drawings

10           A more complete understanding of the present invention may be had from the foregoing and following description taken together with the appended drawings, in which:

Figure 1 is an illustrative showing of a typical aluminum reduction furnace or pot;

Fig. 2 is a schematic diagram of a control system use in practicing the present invention;

Fig. 3 is a graph showing an improvement in efficiency obtainable in accordance with the teachings of the present invention;

20           Fig. 4 is a curve showing the operational relationships of pot resistance, metal height, alumina concentration and efficiency of the current for an illustrative cycle of operations; and

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trolysis.

In the electrolytic production of aluminum, so the current converts alumina to aluminum and some of the is used to convert the anode carbon to carbon dioxide. reaction takes place where the aluminum so reduced is cc back to alumina and carbon monoxide. The total current fore is not used only to reduce aluminum but also for th other reactions. The resulting current efficiency is th of the useful current utilized for reducing alumina to a  
10 in relation to the total current passed to the process.

The alumina charged into the electrolyte prese the pot and the carbon in the electrode, which refers to anode electrode that can be made up of carbon containing briquettes, which due to the temperature of the process fused together into a substantially solid mass, react to aluminum and carbon dioxide by the reaction  $2\text{Al}_2\text{O}_3 + 3\text{C} \rightarrow 4$   
A secondary reaction occurs between the reduced aluminum the carbon dioxide to convert back to alumina and carbon ide by the reaction  $2\text{Al} + 3\text{CO}_2 \rightarrow \text{Al}_2\text{O}_3 + 3\text{CO}$ . There is a th  
20 action between carbon dioxide and hydrogen to produce wa and carbon monoxide by the reaction  $\text{H}_2 + \text{CO}_2 \rightarrow \text{CO} + \text{H}_2\text{O}$ . A dictable reaction rate occurs at the measured gas temper compared to a predetermined reference temperature, such  
by measuring the gas temperature the reaction rate can b

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analysis determined percentages of carbon dioxide CO<sub>2</sub> monoxide CO, compensated for temperature conditions, follows:

$$\%CE = \left( \%CO_2 + \frac{\%CO}{2} \right) \Delta \exp\left(-\frac{B}{T}\right) \text{ to the base}$$

When the current efficiency has been determined, the height or position of the movable anode electrode relative to the stationary cathode electrode, as shown in the example of the Figure 1 furnace, can be adjusted to realize the desired current efficiency through a trial and error operation. The resistance of the pot drops off in the course of the normal electrolysis operation, as shown by the curve of Fig. 4, and it subsequently peaks to indicate when it is time to recharge the pot with alumina to bring the current efficiency back to the desired level. When a current efficiency peak, as shown in Fig. 4, is established by adjusting the anode electrode position back and forth a predetermined small amount to return to the peak condition, and before a rise in the pot resistance is excessive, a controlled searching for and resulting maximization of the current efficiency can be realized. By monitoring the resistance of the pot periodically, a prediction of the ahead of time can be made when it is desired to recharge the pot with alumina to avoid the occurrence of the undesirable anode effect as indicated by a rise in pot resistance. In this way the computer can schedule the recharging of the

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and integrating the effective reduction of aluminum for same pot to provide the sum of aluminum deposited with pot to determine how much total aluminum has been reduced the height of same relative to the anode.

When alumina is charged into a pot, it dissolves the cryolite and forms the desired electrolyte for the electrolysis of alumina to aluminum. The position of the anode relative to the cathode electrode varies the current efficiency; also, if the anode electrode becomes too close to the aluminum level the current efficiency drops off. A minimum current efficiency is established by controlled adjustment of the electrodes by predetermined incremental amounts of alumina <sup>concentration</sup> changes, this requires a change in the relative position of the electrodes; the resistance of the bath also must be considered as, when the alumina concentration goes down, the bath becomes less conductive.

Some objectives of the present invention are to maximize the operational current efficiency, to inhibit the occurrence of anode effect by proper recharging of alumina at a desired time, to control and correct a sick pot condition which occurs when an excessive charge of alumina is added by the electrode to increase the effective resistance of

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Referring to Fig. 2, there is generally shown a plurality of aluminum pots 2, each having an exterior metal shell and being interiorly lined with a suitable refractory material like. The pots 2 each contain a bath 4 of fused-salt electrolyte, such as alumina fluxed with cryolite, and a bottom 6 of aluminum produced by the electrolysis operation, hereinafter explained. Associated with each of the pots is a pair of electrodes 8, 10, in general illustrative form, somewhat modified from the showing of Figure 1, these being connected in series with a direct current power source 12 through conductor lines 14, 16, 18 and 20. In the line 14, there is provided an ammeter 22. Across each pair of electrodes there is provided a voltmeter 24, 26, 28. The series current in each of the pots 2 is the same; and the voltage indicated on each of the voltmeters 24, 26, and 28 indicates the resistance of the bath in its associated pot. This is, of course, dependent upon the relative positions of the electrodes 8, 10 and the content of alumina in the bath 4, in each pot. The above-indicated equipment is conventional and well known in the art.

20 In the practice of the present invention and with reference to the showing of Figure 2, a movable electrode in each of the pots 2 is provided with a hollow metal pipe indicated at 30, by means of which gases evolved during the electrolysis operation can be drawn off from the bath 4.

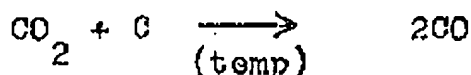
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such connection line and thereby monitor the operation of respective pots. This provides information from which the efficiency of current utilization in each of the pots 2 may be determined. As indicated at 42, this information is fed to the digital computer 44.

If desired, the manner of calculating the current efficiency of the basis of the anode gas analysis can take account the water-vapor content of the anode gas. In other words, the current efficiency can be calculated in accordance with the formula:

$$\%C.E. = [\%CO_2] + \frac{44}{18} [\%H_2O] + \frac{1}{2} \left( [\%CO] - \frac{28}{18} [\%H_2O] \right)$$

where  $[\%CO_2]$ ,  $[\%H_2O]$ , and  $[\%CO]$  are the volume percentage of the various anode surface gases indicated that are found in the respective gas samples from each pipe 30. A correction factor as a function of the reaction temperature can be included in the determination of current efficiency, with the reaction rate a function of the temperature, to correct for the known reducing reaction:



to give a system control equation as follows:

$$\%C.E._{control} = \left( \%C.E._{measured} \right) A \exp\left(-\frac{B}{T}\right) \text{ to the base}$$

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periodically, for example, as scheduled by the computer immediately after aluminum metal has been withdrawn from the pots 2, to check the level of molten aluminum metal therein, inasmuch as with the use of such an inter-operating metal-level-sensing device, the problems associated with providing a level-sensing device that remains open for long periods of immersion in the high-temperature molten metal of the fused salt electrolysis bath are reduced and encountered. As will be explained below, determining the metal level in the pots 2 between such actual measurements can be done accurately by operation of the computer 44. Moreover, within the detector device 54, or if desired, separate means can be provided for sensing the bath temperature

10 metal level in the pots 2 between such actual measurements can be done accurately by operation of the computer 44. Moreover, within the detector device 54, or if desired, separate means can be provided means for sensing the bath temperature

The computer 44 is supplied with stored power limit information, as indicated at 58, such that in the operation of the provided control system, effective use may be made of the available electrical power without exceeding the predetermined demand limit, or with excursions of total power beyond the demand limit being of controlled severity and thus effectively minimized, to the end that a maximum of benefit be obtained relative to electrical power costs incurred in the operation of the

20 tion and thus effectively minimized, to the end that a maximum of benefit be obtained relative to electrical power costs incurred in the operation of the

The computer 44 is operatively connected to

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trode position.

As indicated by signal line 66, computer 44 is connected to a suitable print-out or display device 68, which indicates a desired alumina feed schedule and a suitable withdrawal schedule to guide the activities of a human operator again with the aim that the efficiency of the system is maximized.

The mode of the operation of the programmed computer 44 will now be explained in greater detail.

10 It will be understood, of course, that the exact manner of implementing the computer control of the aluminum-production process may vary in accordance with the hardware already available and selected for the implementation of the various functions mentioned above, but it will be clear to those skilled in the art how, with suitable hardware, to practice the advantages of the control hereinafter described.

20 In essence, the computer 44 sequences the operation of the gas analyzing device 34 through connection 35 and receives a periodic gas-analysis signal for each respect as indicated by signal line 42, and computing from this information for each pot a current-efficiency signal is determined through operation of above equation 2 or equation 3; this signal is then, in turn, both integrated with respect

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a knowledge of the present calculated production of a metal and the predicted integral of the current effic

By comparison of calculated present metal l  
comparing the calculated projected metal level with a  
mined scheduled or reference level that is supplied t  
puter 44 as a part of its stored instruction program,  
or schedule for removal of molten metal from a given  
be determined. Though the metal removal may be done  
ways, one well known practice is to remove molten alu  
10 with the use of a vacuum snorkel arrangement. A comp  
the known electrode position for a given pot 2, and t  
lated level of molten metal therein, will reveal a ne  
moving the electrode or electrodes upward to remain o  
tact with or at a desired distance from the molten me  
in some instances it may be desirable to include in t  
for the computer 44 suitable analysis for and correct  
condition; in most instances, however, this particula  
culty will be otherwise automatically avoided by the  
practice of maximizing current efficiency through aut  
20 changing of electrode position, or by the means provi  
sure of a sick pot, wherein the position of the anode  
in response to a drop in pot resistance and in curren  
ciency.

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from a knowledge of differences in the time values stored in the computer memory, to predict the time, after charging the pot, the onset of anode effect may be expected and accordingly need to charge the pot with alumina. On the basis of prediction, the computer 44 operates the print-out device to indicate to an operator in an out-printed schedule of operation for the next ensuing period of operation, e.g., a period of about 4 hours, the need for charging the pot involved alumina at about the time that the onset of anode effect is expected to occur for preventing the latter effect. C

10 attention must be paid to the amount of molten metal in the pot so that it does not become overfull; it may be desirable in some event to withdraw periodically molten metal and then add alumina shortly thereafter.

The exact manner of programming the computer is subject to some variation, depending upon the importance attached to the various operations in the process. The following are four main considerations here, and they may be ranked differently in different installations, depending upon the practical circumstances involved. If, for example, adequate overlimit power is available and is not especially costly, it may be important, in the order named, to (1) cure sick pot

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stantially less important effect on the overall production of the totality of pots than does, for example, a ratio of one sick pot in five.

Having established priorities among the various considerations mentioned above, persons of ordinary skill in the art may then develop a suitable control program for the system within the scope of the present invention, giving regard to the following further teachings.

When a pot is sick, the bath temperature and current density as determined from current and the voltage between the electrodes, tend to become low, as does the current efficiency. Monitoring for sick pots involves checking these factors against predetermined standards stored in the computer memory, in a desired order, with a corrective sub-routine as previously set forth being initiated whenever the results of the monitoring operation indicates a need for corrective action. The corrective sub-routine involves raising the anode electrode current to increase the resistance, as indicated by the observed voltage between the electrodes to a desired value, or to maximize current efficiency in the given pot in question as determined by anode-gas analysis. Curing or preventing the anode from becoming sick requires the charging of additional alumina to the pot in question. It is a matter of choice whether charging of al

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cost of producing primary aluminum, and control measures may importantly influence the power cost are thus of considerable importance to the resulting economics of the process. It not infrequently happens that a primary aluminum plant is the largest single customer of its local power company, to which its need for power influences the local power company's choice of capacity for power generation equipment. Like other users of electric power are familiar with rate schedules which set a selected demand limit, e.g., for example 200,000 kw, and provide for additional charges if it is exceeded. Such schedules also are based upon the premise that a certain percentage factor, such as 70%, a percentage of the total available capacity over a period will be used by the customer, and provide for additional payments in the event that usage of power exceeds above such level. Another consideration is that, so long as the individual pots of a total line are each operating efficiently, it is best to use as much power as can be had without passing the demand limit, for in that way production can be maximized and costs per unit of production can be minimized.

The nature of the improvement in accordance with the present invention in observance of power demand limit

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As indicated above, the importance that is placed upon the matter of keeping the power used by the pot line limits will influence the stored control program that is used in the computer. Whatever program is used, it is upon periodically monitoring the voltage values from lines 24, 26, 28 shown in Figure 1 to arrive at a total voltage for the line and then multiply this by the line current by the ammeter 22. This gives the instantaneous KVA of the system. The same value can be obtained, without calculations, by using a voltmeter across the lines 14 and 20 to obtain the total voltage value. If KVA is integrated over one obtains a KVAH or power consumption figure. It is of choice whether instances of exceeding the power-demand are to be avoided altogether, or such instances are tolerated to, say, 10% over, and it is a matter of choice the program used shall be one that causes corrective action of some sort to be taken as soon as the load factor for a particular period of time falls below 95%, or one that does not any corrective action to be taken until the load factor falls to some predetermined level such as down to 85%. What is essential, in accordance with the present invention, is that there be provided the control means in conjunction with the aluminum pot line, for computing rapidly the load factor.

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shown in Figure 1 and/or alumina can be added, this be  
either by automatic means or manually on the basis of  
tions that can be made to appear, in accordance with a  
program for the computer 44, on the print-out device 6  
ably, electrode position control is used, as this furn  
particularly fast-acting means of correction, but for  
rection of longer-term departures from the optimal or  
erable conditions defined by the stored program in use  
suitable but slower-acting corrective measures will fi

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As shown in Figure 2 a gas analysis apparatus  
operative with a pipe 110 extending down through the  
electrode 100 to sense the gas forming at the face of  
trode for analysis in relation to percentage of carbon  
and percentage of carbon monoxide. The anode 100 can  
be made up of the well known carbon and sand mixture in  
form of briquettes which, at the temperature of the pr  
becomes a solid mass where it comes in contact with th  
106. The computer can follow a predicted mode of oper  
wherein the control anticipates the current for each r  
20 schedules the operation for recharging each pot by mea  
the resistance across the pot in relation to voltage a  
rent. In this way the pot is run at maximum throughpu

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electrolyte and cathode electrode is proper. Irrespe  
the accuracy of the measurement here provided, and th  
lation of current efficiency CE by the above equation  
paring the change in current efficiency as calculated  
ferent positions of the anode, the anode position for  
current efficiency will be found through the on-line  
tation here provided and in accordance with the illus  
of Figure 5. In this way, periodically, a hunting or  
and error operation is undertaken relative to adjustm  
10 the position of the anode electrode in relation to th  
lyte and the stationary cathode electrode.

If desired a feed conveyor for the alumina  
provided in conjunction with the plurality of aluminu  
pots to feed alumina to each pot in accordance with a  
schedule contained in the memory of the computer. Th  
can monitor the quality of cryolite within each pot,  
changes very slowly, so a sample taken once a day wou  
be adequate. By adding to the bath a few pounds of a  
every predetermined period, such as a fraction of an  
20 concentration of alumina within the electrolyte shoul  
substantially constant and within controlled concentr  
The feed rate of alumina to an individual reduction p  
be determined by the computer or regulated by a manual

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In accordance with the present invention the resistance is monitored to predict changes in the alumina concentration and determine when alumina charges should be added. In addition, the use of off gas from the anode electrode face is utilized to maintain current efficiency at a desired level by adjusting the anode cathode distance to effect an increase overall energy efficiency.

It is clear that the suggestive method of measuring the analysis of gas leaving a pipe which is embedded in the anode electrode will give a sample of the gas as actually formed at the face of the electrode. The sample should not become contaminated with ambient air. The composition of the gas should truly reflect the reactions occurring at the electrode and not require correction for ingress of nitrogen.

The computer calculates the current efficiency upon gas analysis in accordance with the above equations as follows:

$$\%CE = \%CO_2 + \frac{\%CO}{2}$$

This suggests that the content of carbon dioxide, carbon monoxide and, if the third reaction relative to hydrogen is included as represented by above equation (3), the moisture content of the gases coming off the face of the electrode should be measured. Furthermore since these equations are in terms of weight, the percentage volumes as measured

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Similarly electrode reduction rate is also proportional to the same product, therefore:

$$\sum_0^t A_1 = K_1 \sum_0^t I(\%CE)$$

The theoretical potential for the electrolysis of alumina is about two volts. If current efficiency is used to control electrode position, the constraint on the potential should not fall substantially below two volts, i.e., the electrodes must not be so close to the metal bath that the resistance through and therefore potential across the bath are less than that required for electrolysis, no resistance across the bath be so high that excess energy is used in warming up the bath and probably increasing the rate of the above described second reaction.

Maximum current efficiency will lie somewhere between these two constraints. It is also likely that the current efficiency plotted against electrode position will show a substantially flat peak as shown in Figure 4, so that manual control of electrode position is suitable. Further, the volume of aluminum produced in the given time  $T$  will be greater than the volume of electrode consumed. Between the bath, therefore, one would expect the electrode to

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of time as shown by curve 206. The shape of the resist. curve is not changed by a movement of the electrode but is displaced. Anode effect is revealed by a sharp rise in resistance across the pot towards the end of the cycle between  $t_2$  and  $t_3$ , and accompanied by a sudden fall in current efficiency which indicates that the pot needs recharging with Al. A sick pot (not shown in Figure 4) would be revealed by a reduction in the resistance, accompanied by a falling current efficiency; this indicates the pot is overfull of Al and the electrodes should be raised either until the resistance falls to a normal value or the current efficiency is at its present maximum obtainable.

Clearly the maximum current efficiency obtainable at any time will vary with current, the amount of cryolite concentration of alumina in the bath and the bath temperature. When a new charge of alumina is first inserted some time must be used in warming up the new material as well as in recharging, this is particularly if the anode effect has been suppressed. Feeding new material at an earlier point in the cycle is possible if the bath temperature has not risen excessively.

Some basic objectives of the present control system may be stated as follows:

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individual pots will be (a) current, (b) resistance, current and individual pot voltage, (c) current efficiency from gas analysis, and (d) bath temperature.

At regular intervals, for example once per reading will be taken on the liquid metal level and of the cryolite bath. The liquid metal level can be at once every time a pot is tapped. By experiments, relation can be made between maximum attainable current efficiency, the bath resistance, and the aluminum concentration at different current levels. Furthermore, the width of current efficiency curve peak, as generally shown in Fig. 10 in terms of corresponding anode electrode travel will be determined at the middle of the cycle, i.e., a predetermined alumina concentration, for various values of electrode current. All of the above data will be stored in the memory of the computer.

Assume that an individual pot is on manual operation and it is desired to place it under computer control. An operator will adjust the electrode position in accordance with his own past successful experience and will now reach a good pot. The computer control system is then made operational and assume control of the operation. The computer will maintain the temperature of the bath at a predetermined level.

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of the metal bath. Should this be accompanied by the of the current efficiency curve as shown in Figure 5 a desired value, the nominal position of the anode, w computer will be hunting about this nominal position, raised by a corresponding amount.

As the batch proceeds, the differential of times the percent efficiency current efficiency  $\%CE$  computed, and when this is equal to zero, it will indicate beginning of anode effect. There is a fixed ratio  $\frac{t_2}{t_3}$  10 reference to the illustration of Figure 4, which will time when recharging should take place to be predicted values of  $t_1$  and  $t_2$  will be noted at specified values differential  $\frac{d}{dt} (I \cdot \%CE)$ , since these have corresponding alumina content values. Thus by noting  $t_1$  and  $t_2$  for 20 corresponding values of  $\frac{d}{dt} (I \cdot \%CE)$ , the time  $t_3$  may be determined and the recharging of the pot scheduled accordingly. Prediction will be on the basis of production rate remaining unchanged. Should the electrolyzing current change, the recharging schedule will have to be brought forward or delayed by a corresponding amount.

For the detection of sick pots, if an excess of alumina is charged at the beginning of the cycle, an excess of alumina fall into the pot at sometime will

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electrodes of one pot are moved, the control of line at a substantially constant value is highly desirable also makes more accurate the prediction of recharging for scheduling. To make this prediction at an early the cycle, i.e., as soon as the pot has been restabil charging, the values of  $t_4$  and  $t_5$  at specified values can be noted, and  $t_3$  predicted from the ratio:

$$\frac{t_5 - t_4}{t_3 - t_5} = K, \text{ where } K \text{ is a known relations.}$$

the past occurrence of the anode effect condition.

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In general, the pot control program by the is as follows:

1. Initiated by operator after recharging alumina.
2. Examine bath temperature and check for :
3. If pot is sick, raise electrodes until is adequate. Otherwise pass to (4).
4. If pot is normal and stabilized, optimi: current efficiency.
5. Begin integration and differentiation o:
6. If bath height rises excessively, deteri

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$\sum_t I \%CE,$  raise anode electrode an amount proportion

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and include  $\sum I \%CE$  and  $\frac{d}{dt} (I \%CE)$ .

12. Print out each hour the present schedule three hours. This should take into account present all charging mechanism position and location of the pots and alumina in the lines. Predetermined tolerances (plus or minus) are allowable on the recharge time.

The primary purpose of the demand control is to maintain a high load factor and to control the KVA demand. The total KVAH over the demand period is to the greatest extent neither above nor below the given level. At the beginning of a demand period a reset pulse is received from power company metering. This indicates to the computer that it should initialize all programs and counters for the first demand period. As the power is used by the plant, representing units of KVAH are transmitted to the computer. The KVAH used is continually accumulated and compared with predetermined high and low KVAH usage rates. If the actual consumption exceeds either of these limits some action is taken to increase or decrease the KVA into the pot line. This is done by adjusting the taps on the line transformer. If predetermined limits, by means of contact closure output, are exceeded the computer. The contact closure output energizes the tap changer control which moves the tap to a new position.

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change or modification therein which may be made witho  
parting from its spirit and scope.

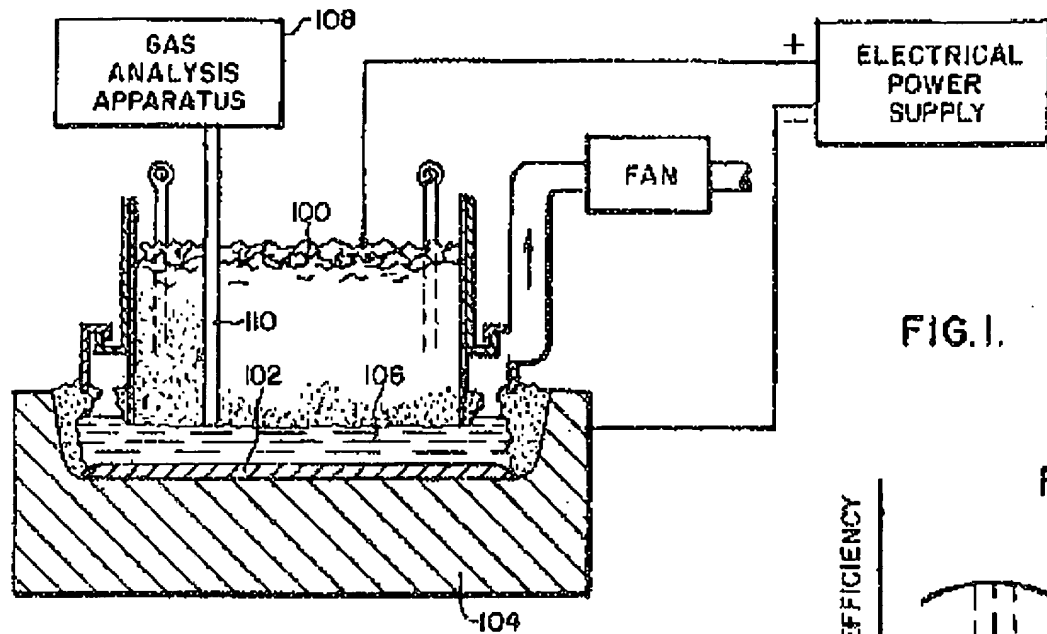


FIG. 1.

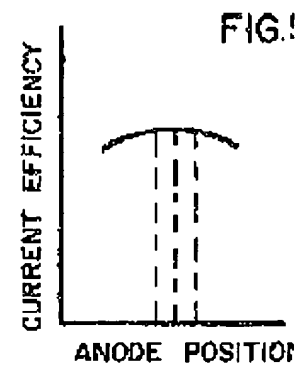


FIG. 2.

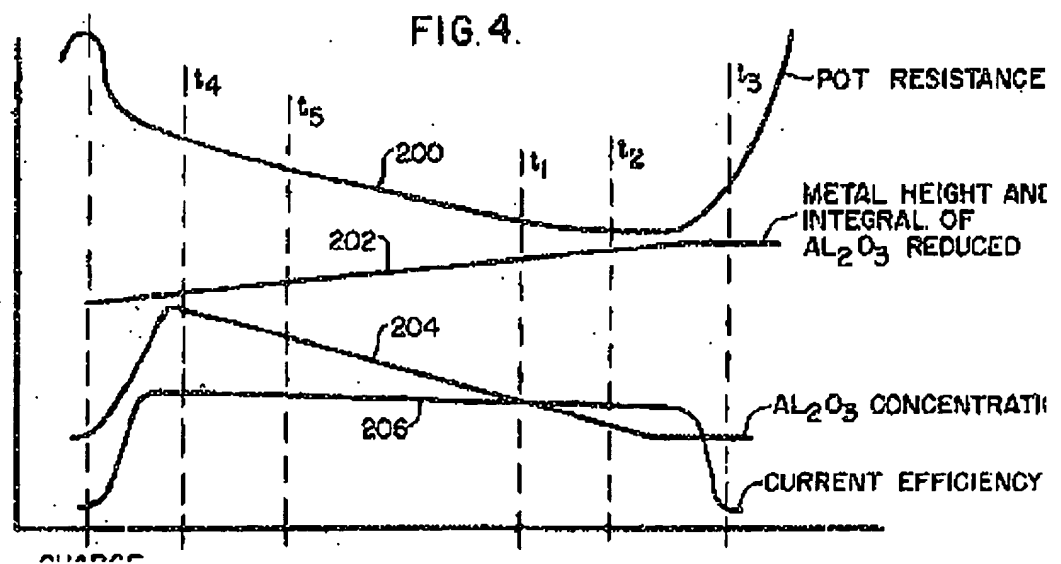
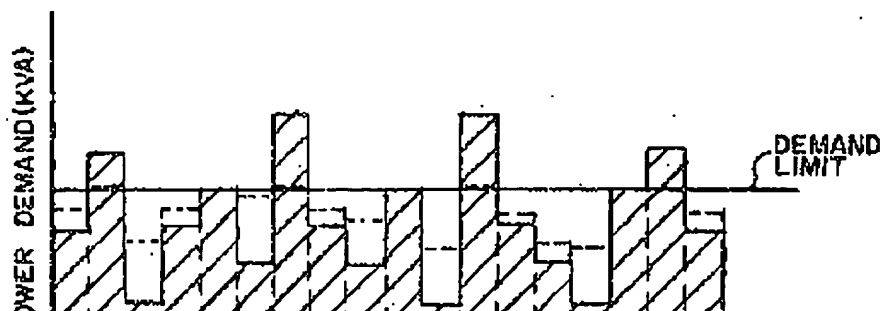
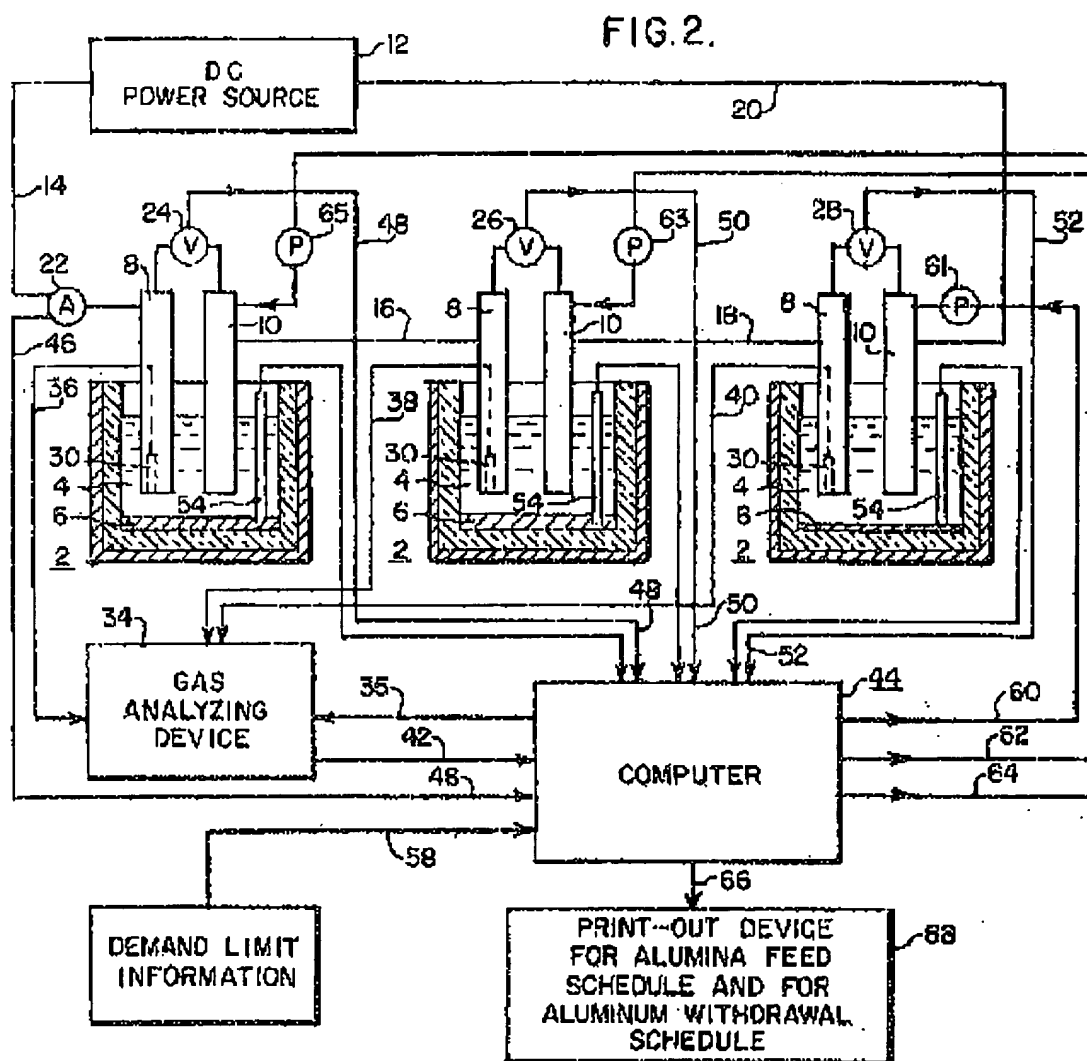


FIG. 4.



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